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studies support the contention that these are merely sequential phases in a single disease process. The policy of treatment of preclinical carcinoma is outlined, as are the results obtained.

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REVIEW ARTICLE

Observation of Children's Teeth as a Diagnostic Aid: A Review

Part I. Dentition in the Assessment of Development

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ABSTRACT

The accuracy of information obtained from such a simple procedure as looking in the mouth as a measure of child development led to this review. The relationship between dental and physical development has been known for many years. Methods of assessing maturity by counting erupted teeth are described. Measurements taken on two boys illustrated this hypothesis, and from these the close correlation between height and weight, bone age and dental age is shown. It is suggested that physicians and dentists should record the number of erupted teeth on interval examinations, since the pattern of eruption and calcification of teeth may present the first indication of developmental retardation.

PHYSICIANS, dentists, and others concerned with child health need to be aware of certain measures of growth and development that will aid in the early detection of chronic disease states and growth failure. The impact of many crippling illnesses has been reduced by the practice of modern preventive medicine. This leaves the health professions responsible for the care of increasing numbers of children with chronic disability states. In these, recording developmental measures can be of assistance in assessing treatment over a long period.[1] Height and weight measurements and skull circumference for the younger child are now documented in a longitudinal manner by the physician, much as temperature was once taken. When abnormal growth or deviation of growth through disease is suspected, our knowledge of the accurate relationship between bony development at the wrist[2] or knee,[3] chronological age, and height-weight records leads us to take appropriate roentgenograms. The bone age is used to judge whether somatic and physiologic maturity are synchronous and allows for prognostication of future growth likely to occur.

Why teeth have been so widely overlooked as an index of physiological maturity is difficult to explain. A number of impressive studies have reported measurements of time of eruption,[4] root formation,[5] cusp formation,[6] and numbers of deciduous and secondary teeth[7] present in the mouth at various ages. These demonstrate that dental development is certainly closely related to the development of a child as a whole. The measure of maturity by the simple techniques of observation and radiography in the mouth is more productive than many complex laboratory techniques.

History

Sporadic interest in the time of eruption of teeth has been noted for more than 100 years. In the 1830's, when child labour laws were being debated in the British House of Commons, it was pointed out by one of the Members that parents were exploiting their children by falsifying their age. It was suggested by the Honourable Member that by adopting the technique of horse traders, the teeth could be used as an accurate determinant of the age of the child.

Cattell[4] published in 1928 a monograph entitled "Dentition as a Measure of Maturity" in which he

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compared many milestones of development of the children with growth of their teeth. Within this monograph is reported the pioneer work of a number of investigators. Röse, in Germany in 1908, studied tooth development in 41,000 children. Beik, also from Germany, observed in 1913 that "the dentition is the best single indicator of the stage of physical development—or physiological age". The studies of Matiegka of France in the same era established a fairly accurate index of physiological age on the basis of the numbers of erupted teeth. In America, Cattell's monograph records similar studies by Bean, who stated: "The teeth are more convenient and more exact as a means of determining the physiological standard than stature, or weight, or the growth of bones, or secondary sexual characteristics, etc., and they may be of greater value than any other means that can be utilized. The teeth can be seen, counted and identified by almost any one after a little experience and they are either present or absent, therefore, very definite."

More recent publications have explored various factors which might influence the time of eruption and have presented numerous refinements, such as the rates of calcification of the crowns[6] and rates of root growth.[7] These investigations have all shown a positive correlation between dental development and other measures such as height and weight which should be regularly recorded for our patients.

The Tooth as a Vital Organ

Teeth are derived from the same embryological cellular elements as hair, skin and nails. The various metabolic or pathological disturbances that might occur during the period of their formation can be reflected in both their morphological characteristics and rate of growth.

Each individual tooth passes through four successive periods of development in its life cycle.[8]

1. Growth.—Tooth formation commences at about the 50th day of gestation. Epithelial cells differentiate histologically during this process of multiplication to form the bell-shaped enamel organ. The inner layers of cells become the *ameloblasts* that form the enamel. The peripheral cellular layers become *odontoblasts* that are responsible for the formation of the dentine. The boundary of these two cellular layers, the future dentinoenamel junction, establishes the basic crown form. Enamel and dentine are laid down in incremental layers that resemble rings of a tree.

2. Calcification.—The calcium salts are deposited in the matrix of the enamel and dentine. The mineral structure of the root is established synchronously with the outward movement of the crown and its eruption into the oral cavity.

3. Eruption.—The breakthrough and appearance in the oral cavity.

4. Life span.—When the tooth is in the mouth, the coronal portion is gradually worn by attrition.

The various teeth of the dental arches are formed and calcified at different times. The crowns of all the deciduous teeth commence their calcification *in utero*. An indelible record in the tooth in the form of the *neonatal* line results from the disturbance of calcification around the time of birth. These lines are found in the crowns of all deciduous teeth and are normally seen only microscopically. Their accentuation varies with the degree of trauma or difficulty of the subsequent adjustment at the time of birth. When the perinatal period has been difficult, for example, when complicated by anoxia, the neonatal lines may be observed with the eye. Lines may occur on the enamel of teeth as the result of anoxia to the fetus *in utero*. Hence the position of lines on the tooth may be used to determine whether the trauma occurred prenatally or at the time of birth.

The formation of the permanent first molars and the central incisors is initiated during the first six months of life. There is a range of physiologic variation in the time of formation as well as their subsequent calcification and eruption. By 2½ to 3 years all the permanent teeth, with the exception of the third molars, are in an early stage of growth. The crown formation of teeth is an orderly process that commences mid-way *in utero* and continues throughout childhood. The process is complete upon the eruption of the third molars, which occurs during the latter part of adolescence.

During their life span the teeth do not remain static. Studies in which radioautographic techniques have been utilized have demonstrated the fact that mineral ions pass continually into and out of all hard tissues of the body.[9]

MEANS OF ASSESSMENT

Deciduous or Primary Teeth

When examining a child, if the numbers of primary or deciduous teeth erupted are noted in the medical record, a useful reference of development is obtained. The routine "well baby" examinations are designed to focus early attention upon developmental problems and are too frequently terminated with completion of immunization procedures. One technique is to count the number of teeth erupted in the maxillae and the number erupted in the mandible and to mark this as a fraction (e.g. $\frac{6}{7}$). Another means of recording the teeth present at any time is by use of letters in a fraction, e.g. $\frac{\text{cba}}{\text{dcba}}\Big|\frac{\text{abc}}{\text{abcd}}$. By observing the number of erupted teeth, attention will also be drawn to enamel defects. The causes of enamel hypoplasia will be discussed in Part II of this review.

The rare problem of erupted teeth (lower deciduous incisors) in the newborn, which are called *natal* teeth, or if erupting during the first 30 days, *neonatal* teeth, has been recently reviewed by Gardiner.[10] Their incidence is reported as one in

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TABLE I.—NUMBER OF TEETH ERUPTED AT DIFFERENT AGES*

Age group				*Percentiles*				*Means*		
Midpoint	*Range*	*N*	*Minimum*	*25*	*50*	*75*	*Maximum*	*Male*	*Female*	*Both sexes*
months	*months*									
Under 4 months		330	0	0	0	0	0			
5	4.5 - 5.5	86	0	0	0	0	4	0.4	0.2	0.3
6	5.5 - 6.5	95	0	0	0	2	6	0.8	0.6	0.7
7	6.5 - 7.5	77	0	0	0	2	6	1.4	0.8	1.2
9	8.5 - 9.5	73	0	1	2	4	9	3.2	2.8	3.0
12	11.5 - 12.5	56	0	4	6	8	17	6.6	5.8	6.2
15	14.5 - 15.5	66	3	7	9	12	16	10.2	8.2	9.2
18	16.5 - 19.5	124	4	12	13	16	18	12.8	13.2	13.1
21	19.5 - 22.5	119	4	14	16	16	20	15.6	15.4	15.5
24	22.5 - 25.5	110	8	16	16	18	20	16.5	16.7	16.6
30	28.5 - 31.5	70	12	18	20	20	20	19.0	19.0	19.0
Over 34 months		110	20	20	20	20	20	20.0	20.0	20.0

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every 3000 live births. Some children shed these teeth in the perinatal period, but the majority remain until 5½ to 6 years when they are exfoliated.

An atlas relating the time of eruption of deciduous teeth in percentiles with other measures of height, weight and bone age would be a helpful guide to dentists, physicians and others working with children. Such an atlas has not to our knowledge been published. Tables have been drawn up by Meredith[11] from studies of population groups in Boston, Southern Ohio, Iowa, and New York, etc., showing the time of eruption in relation to age as percentiles for both sexes (Table I). These studies indicate that teeth rarely erupt before the 4th month. The mean age of eruption of the first tooth is 7½ months.

The pre-school years are the period when early recognition of disability states is most helpful. Because of the availability of school-age children, there are numerous studies on dental development centred on the eruption of permanent teeth.[4, 14, 17, 20] Comparable studies dealing with deciduous tooth eruption have been restricted by limited contact between physicians, dentists, and the pre-school-age child. Though limited, these studies have shown that both primary and secondary teeth erupt in a characteristic sequence. The usual order of the eruption of deciduous teeth is incisors, first molars, canines and second molars. The first tooth to erupt in about 95% of individuals is a lower central incisor. A study of the eruption of deciduous teeth in monozygotic and dizygotic twins by Hatton[12] and the most careful work at the Fels Research Institute by Lewis and Garn[13] support the hypothesis that tooth formation is to a large extent gene-determined. The higher correlation of time of eruption is found, as might be expected, in monozygotic twins.

The finding of any delay in dental eruption beyond two standard deviations for an age group should prompt one to explore other factors of physiologic maturation. Nutritional problems before birth and in the perinatal period, prematurity, and developmental diseases (ectodermal dysplasia, etc.) should be considered in children who are experiencing delayed eruption of deciduous teeth.

Permanent or Secondary Teeth

The eruption of permanent teeth, if observed and noted by a physician or dentist in his assessment of the pre-school and school-age child, can provide accurate knowledge of development. A close tie between the pattern of tooth eruption and the skeletal maturation and height-weight gain is to be expected, since both are occurring as components of growth and development. The studies of earlier authors showed that the dentition could be used as a measure of physiological maturity.[4, 14, 17] Some well-devised observations have recently demonstrated in permanent teeth the correlation that exists between skeletal and dental maturity.[5, 7, 13, 15, 16] Premature extraction of deciduous teeth may introduce slight variables in eruption of permanent teeth. With improved dental care this becomes less significant as a source of error.

To illustrate the practicality of the hypothesis of dental eruption as an index of development, a random selection was made of two Grade I pupils. The teacher chose one boy from amongst the larger children and the other from the smaller. The birth dates of these children by coincidence fell within 15 days of each other. Figs. 1a and 1b show the various measurements made on these boys. The number of erupted permanent teeth and the crown development as portrayed in lateral oblique jaw radiographs closely correlate in each case with bone age at the wrist and height and weight. In the larger boy (M.M.), whose weight is above the 97th percentile and height on the 90th percentile, the permanent first molars of both arches and the mandibular central incisors are erupted $\left(\frac{2}{4}\right)$, bone age at the wrist is 7 years, with the left lateral oblique jaw radiogram indicating a dental age of 6½-7 years. The smaller boy (L.L.) has a weight and height both on the 25th percentile; there are

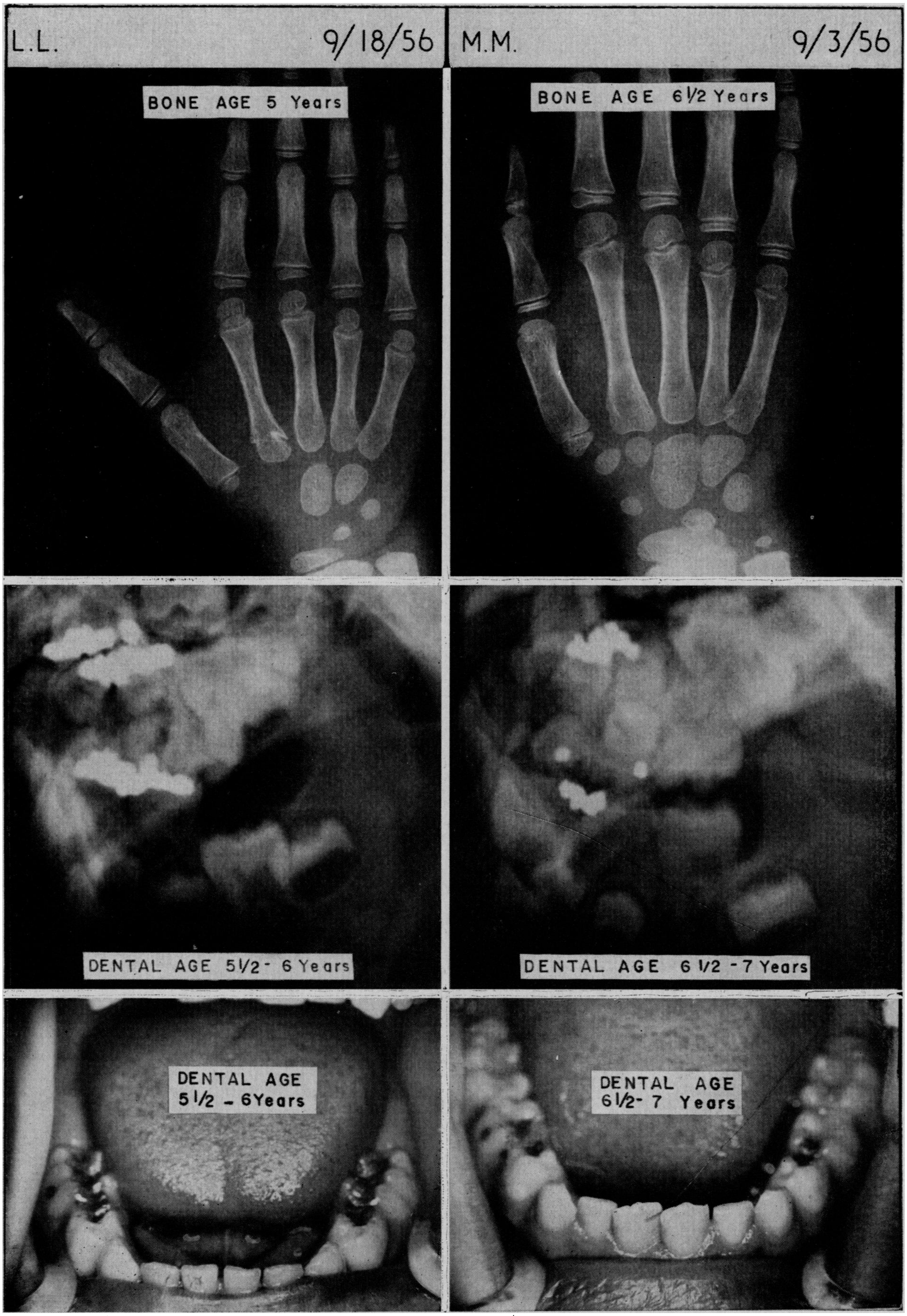

Fig. 1a.—Close correlation of bone age, dental age, and dental eruption is shown in each child. These measures also demonstrate the normal variation in the same chronologic age. Repeat measures make an accurate prediction of the child's growth pattern.

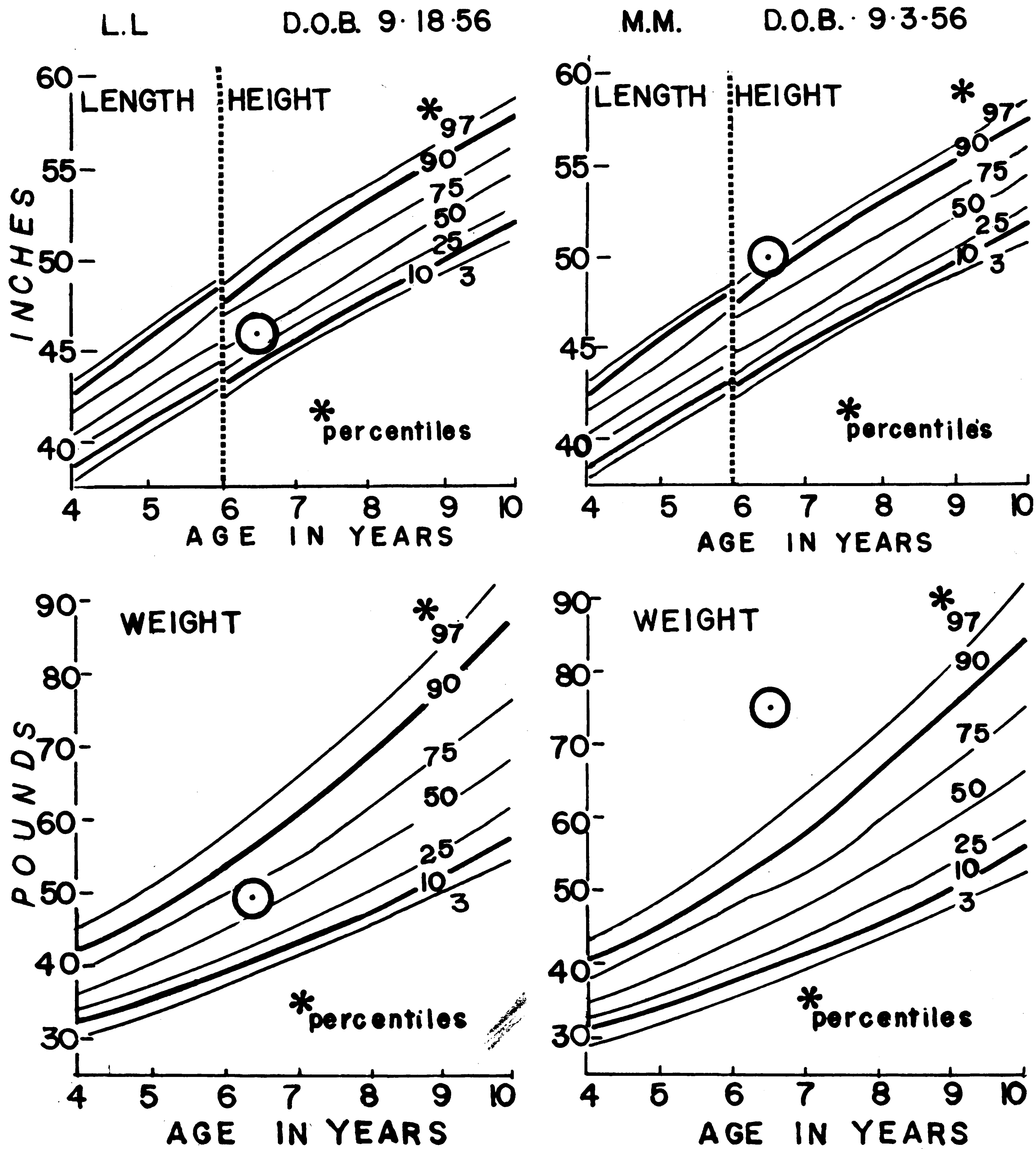

Fig. 1b.—Difference in somatic growth plotted on the Anthropometric Chart of the Children's Medical Center, Boston, H. C. Stuart.

no permanent teeth erupted $\frac{(0)}{0}$, the bone age at the wrist indicates a skeletal age of 5 years and the left lateral oblique jaw radiogram shows a dental age of 5½-6 years. Thus these boys with comparable chronological ages demonstrate the normal spectrum of developmental measurements and the high degree of correlation of somatic, dental and skeletal growth. Repeated measurements of dental maturity allow as accurate a prediction of the child's future pattern of growth as other indices.

The degree of variability in time of tooth eruption when related to "bone age" has greater latitude than lateral jaw radiographs used to assess cusp formation, crown completion and root development[18] of human molars. Perhaps some confusion has arisen by the need of the orthodontist to predict permanent tooth emergence in order to initiate treatment. The physician, on the other hand, is desirous of an index that will alert him to significant deviations of development by noting numbers of erupted teeth. On a population of 275 children followed longitudinally, Lewis and Garn[13] compared eight different measurements commonly used as indices of maturation. The relative variability

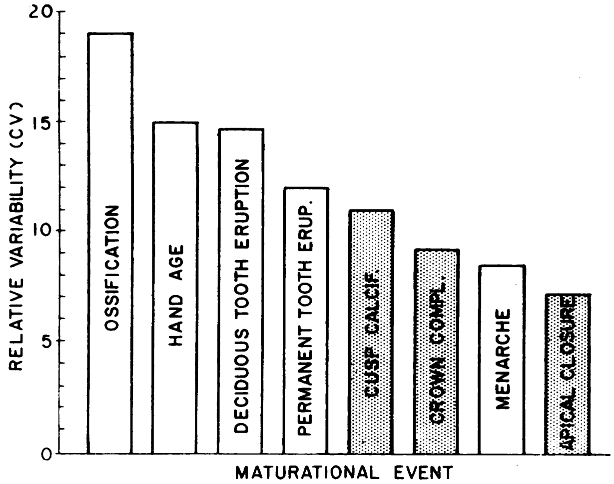

Fig. 2.—Variability[1] of tooth eruption as compared to other measures of maturity. (Reprinted by courtesy of *Angle Orthodontist*, 30: 74, 1960, with the permission of A. B. Lewis and S. M. Garn.)

(coefficient of variability) of permanent tooth eruption compared to the other measurements, on the basis of chronological age, is shown in Fig. 2. (Ossification refers to the appearance of 36 ossification centres—Fels Research Institute.) The information obtained from the number of hand-wrist ossification centres present at a given age, and from a single oblique jaw radiogram, has been shown to be of equal value in predicting future development.[19] Another study on older children found a high positive correlation between the degree of calcification of the mandibular third molar and the skeletal and chronological age.[16] Lauterstein[5] showed a close association between root age of the first permanent molar and bone age, and also between root age and number of erupted permanent teeth.

The mean numbers of erupted permanent teeth in relation to chronological age and skeletal maturation, as reported by Sutow, Terasaki and Ohwada,[15] demonstrated significant *sex differences.* The girls at each age level had more erupted permanent teeth than boys of the same age. Other authors[13, 18] support this variation, and Fanning,[20] in the careful collection of longitudinal data, has worked out percentile tables with sex difference based on tooth formation recorded by lateral jaw radiographs. The widely used "Children's Medical Center, Boston—Anthropometric Chart", by H. C. Stuart, takes into account the predictable deviation of the measurements of boys' and girls' heights and weights, and records these data on separate grids. This study also demonstrated that the skeletally advanced children have a greater number of erupted teeth than the skeletally below-average children.

Indices of tooth formation (obtained by lateral jaw radiograms), as represented by the three shaded areas, are shown to be the most accurate index of physiological age (Fig. 2). Deciduous and permanent tooth eruption patterns recorded over a number of years are as useful as repeated estimations of bone age at the wrist as measures of maturity. The orthodontist and pedodontist can thereby be expected to focus more interest on time of tooth emergence as predicted by the study of root development.[7] The degree of correlation between dental age and skeletal age[21] is such that the use of cephalometric x-rays and the measure of the total amount of calcification of the permanent dentition of one quadrant of the jaw provide data as accurate and useful as Todd's Atlas of Skeletal Maturation.

SUMMARY

How to use the pattern of eruption of deciduous and permanent teeth as an indicator of development is demonstrated by a review of the relevant literature. If the physician makes a habit of observing the dentition, noting the time of dental eruption, along with keeping height and weight records, a valuable diagnostic sign is brought to his attention and will stimulate study of children with development problems.

Since the dentist will know the age of the child, his observation of eruption pattern and calcification of teeth allows him to become aware of developmental problems such as dental immaturity and assist the family by alerting their physician.

This article demonstrates the need of an atlas of dental development for use as an index of maturity.

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